Cochlear implants are devices that are used to artificially excite nerves with patterns of stimulation that convey speech, emotion, and environmental sounds when a person's inner ear has been destroyed by disease or not developed at birth. In this situation they cannot benefit from the amplification of sound with hearing aids.

The inner ear is a small fluid-filled shell-shaped chamber which contains a membrane that vibrates in response to sound. The vibrations are transmitted to hair cells resting on this membrane. Hairs of these cells transduce mechanical vibrations into electric signals which excite auditory nerve fibres leading to the brain. The membrane also acts as a filter so that high frequency sounds produce a maximal disturbance near the round window and low frequency sounds a maximum more distantly at the apex. Coding of frequency may occur in one of two ways, firstly in a temporal code, the brain deciphering the signal on the basis of timing of nerve action potentials, or secondly on a place basis depending on the site of stimulation within the brain. For place coding the brain cells are arranged so that a frequency scale of units' responses occurs.

The challenge facing cochlear implants some years ago was how to accurately simulate the coding of frequency and intensity by the small number of electrodes when there is normally a very complex arrangement of hair cells and nerve fibres. As a result of research in Melbourne we developed a system for analysing speech that enabled our initial patients to understand running speech. The initial speech processing strategy extracted one important parameter of speech necessary for intelligibility and presented this on the basis of place coding within the cochlear and used rate of stimulation to convey voicing. The prototype device worn by the first patient is shown in Figure 1.

As a result of research in Melbourne we developed a system for analysing speech that enabled our initial patients to understand running speech. The initial speech processing strategy was developed at the University of Melbourne. How the system operates is illustrated diagrammatically in Figure 2. Sound waves are picked up by a microphone and converted into electrical signals. These are sent to a speech processor which is worn by the patient. This decodes the signal, selects out the appropriate features, produces a code and also maps this for the particular requirements of the individual in terms of threshold and dynamic range of simulation. This signal is then transmitted through the intact skin by radio waves to an implanted receiver-stimulator section which in turn decodes the signal and presents patterns of electrical stimuli to different electrodes within the inner ear. Power to operate the device is also transmitted through the intact skin so that no implanted batteries are needed. This prototype speech processing system and speech processor (Figure 2) was developed industrially by the Australian Biomedical firm Nucleus, also the holding company for Telectronics who had pioneered pacemaking
Cochlear implants were used on children after initial evaluation on adults. Children, however, presented special problems (needed to be considered before undertaking the procedure. First, when they are born, deaf or lose hearing early in life their auditory pathways have not been exposed to sound. This susceptibility is very important in maintaining certain essential contacts between the neurons in the auditory pathways. These contacts are not made during the early development of speech perception and are thus processing for children who have never been exposed, are different. Furthermore, children who have not developed spoken language are not able to adequately pronounce speech sounds and thus, language development suffers as well. Few deaf children ever reach the normal level for age performance with the spoken or signed English language. Another difficulty that has to be faced in considering children for cochlear implants is their education placement. Some children with profound hearing loss are taught in an auditory-oral, or auditory verbal, environment in which they are encouraged to use any residual hearing they might have to develop a hearing aid and learn to combine that with reading and writing.

At the same time they are given training in the production of speech sounds. On the other hand, other children are taught to learn sign language of the deaf, called Auslan in Australia. This is a system of signs that contrasts meaning but is not consistent with the grammar of the language and does not emphasize combined use with lip reading. It is a system of signs that needs to be learned and understood by the person communicating with the deaf child. As cochlear implants provide auditory stimulation it is important that the child has learned in an auditory-verbal, or total communication environment with emphasis on auditory stimulation rather than communication from a sign language of the deaf background. Certainly they should not be educated with sign language of the deaf when hearing has been formally restored.

Another issue of importance with children is the head size and head growth. It was important to make sure that head growth in infancy to later childhood would not result in the electrode being pulled out of the inner ear, and secondly that the implant procedure itself would not interfere with head growth. In addition, infants and young children are very prone to middle ear infections and it was seen as important to make sure that the implant procedure and healing around the entry point into the inner ear would not lead to a pathway for infection to reach the inner ear, leading to labyrinthitis and possibly even meningitis. These bimetallic issues were studied at the University of Melbourne over more than ten years, and more recently, as a part of a five-year U.S. National Institute of Health's contract. It studies it was shown that head growth, although significant, so not lead to any difficulties providing there was adequate redundancy in the lead wire allowed between the point of exit in the inner ear and the package, and that the surgeons did an appropriate configuration that would not be bound in tissue. Also the scaling around the electrode track as it entered

Figure 2.
Ear development was found to be adequate, particularly if this was
repaired with a fibrous tissue autograft.

Finally, there are ethical issues of relevance in the case of children
and these concern the rights of parents to act on behalf of their
children. Most profoundly deaf children are born into the families
of hearing parents and these parents in general wish their children
to have the opportunity to hear and participate in the hearing
world, rather than to be made to learn sign language of the deaf.
The most plausible option is to provide a cochlear implant at an
early age while the brain is still maturing so that they have a better
opportunity of learning to understand speech. Later on they will
take the choice of learning sign language of the deaf if they so
desire. They cannot however learn to hear speech if sign language
of the deaf is taught in the early years and an implant is offered at
later stage.

The program to use multi-channel implants for children was
developed firstly at the University of Melbourne and the Royal
Victorian Eye & Ear Hospital. Children only received an
implant after the device had firstly been shown to be effective for
severely profoundly deaf adults. It had not been shown to be effective
in profoundly deaf children. The first child to receive the device
underwent operation in 1984. This was a teenager who had developed
deafness from meningitis at an early age. The results were
encouraging but limited (obtaining open-set speech recognition
scores that one might expect because of the late stage of the operation to
be undertaken).

Then it was necessary before operating on younger children to
develop a device that was smaller and that could be fitted into the
thinner bone structures without excessive protrusion, as well as
being a better system for attaching the external transmitter coil.
The previous device had required a headband, but in the new
transmitter-stimulator developed by Cochlear Pty Limited in
cooperation with the University of Melbourne, there was a magnet
attached with the device that would allow the external coil with
magnet to be easily inserted and worn. This new device was
introduced on a ten-year old boy at the University of Melbourne in
1985 (Figure 3). A younger child of two was operated on in early
1986 in the US, in Alabama, and then a five-year old boy received
the implant in Melbourne in April 1986. The initial results on all
three patients were encouraging and as a result a clinical trial was
undertaken by the U.S. FDA and extended to Sydney and centres
in the US, as well as Germany. As a result of this clinical trial,
the 1982 speech processor was finally approved at the FDA in
1984 as safe and effective for use in children. It was found that
approximately 50 percent of these children were able to get some
open-set speech recognition using electrical stimulation alone as
compared to hearing normal case children, and many but not all, were considerably
biped with the device as a lip reading aid. This was the first
cochlear implant of any sort to have been approved by the U.S.
FDA or any other world health regulatory body for use in children.
Further development of the cochlear implants for children is
ongoing with the aim of providing a hearing aid to all children who
have residual hearing to be aided.

Cochlear implants have now been clearly established as providing
speech reception, speech production and language benefits to
profoundly deaf children. It has also been shown in studies that
children do better if they are operated on as young as possible and
they need to have auditory oral education in a favourable home
environment. Further improvements in speech processing should
further improve the benefits that children obtain.

Figure 3

of course helped severely profoundly deaf children with some
residual hearing to be aided.

Since the FDA approval, further research has been undertaken
with the implant in children, and it has been found that the
improved strategies that were developed and established on adults
were also effective in children. Most of the children were
subsequently converted over to the Multipeak strategy and more
recently a clinical trial has been undertaken at the Universities of
Melbourne and Sydney to compare the benefits of the new Spectral
Maxima Strategy with the Multipeak device. This has been part
of joint research undertaken by the Cooperative Research Centre
for Cochlear Implant Speech and Hearing. This has shown that
the children obtain significant benefits from a change in speech
processing and particularly hear better in the presence of noise.
Recently the results of an NIH supported study on the Cochlear
Pty. Limited multi-channel implants, carried out at the Central
Institute of the Deaf in the U.S., was reported. The cochlear implant
was installed in one matched group of children and the results were
compared with the use of a hearing aid in another group and tactile
aids in a third group. Results showed clearly that the Cochlear Pty.
Limited multi-channel cochlear implant gave better speech
perception, speech production and language skills than the
other aids.

Cochlear implants have now been clearly established as providing
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profoundly deaf children. It has also been shown in studies that
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they need to have auditory oral education in a favourable home
environment. Further improvements in speech processing should
further improve the benefits that children obtain. Further research
should also study why some children obtain better results than
others and on how best to habilitate the implanted children.
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Title:
Cochlear implants in children

Date:
1995

Citation:

Persistent Link:
http://hdl.handle.net/11343/27459

File Description:
Cochlear implants in children

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